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THE RELATIONSHIP BETWEEN INTERIOR DESIGN IN BUILDING AND ARTIFICIAL ILLUMINATION

By JOHN W. T. WALSH, M.A., D.Sc. *(Fellow)*

(Paper read on February 27th, 1945.)

Introduction.

There will be nothing novel in this paper. Most of it, in fact, will be very familiar to the illuminating engineer or to the architect, or both; but here I will venture to suggest that there is a real danger in familiarity. Not, in this case, the proverbial contempt but a too facile acceptance of a method or, shall we say, a formula or set of figures without that appreciation of their basis which is necessary to ensure that they will always be correctly used, and which may even sometimes give them an unexpected and valuable significance.

It has been said that most illuminating engineers suffer from foot-and-candle disease, and I believe the jibe has not been entirely unjustified, so in this paper there will be no mention of foot-candles. We shall, for the most part, be thinking of the light output from lamps and how it can best be used to light the interior of a building. Light output is measured in lumens, and illumination is nothing but the arrival of some of those lumens at some surface or other. The value of the illumination is, in fact, measured in terms of lumens per square foot, and so when we find in the I.E.S. code that sustained reading, for instance, requires an illumination of 8 to 15 ft.c., that means that we must provide 8 to 15 lumens per sq. ft. on the surface of the book or newspaper. It is, I think, a pity that this simple connection between the light output of a lamp and the illumination of an object has been so obscured by the employment of two units having names from which the connection is entirely absent. Let us reform; l/sq. ft. is not much more cumbersome than ft.c. and its employment in this paper will demonstrate how simply it lends itself to any discussion of lighting principles.

Lighting Requirements.

In the recently published report, "The Lighting of Buildings," there is a list of the main requirements, as regards lighting, in school classrooms, and for the most part this list, with very slight modifications, applies equally to almost any type of interior. It is as follows:—

(a) Adequate illumination.
(b) Proper design and placing of light sources so that they do not cause distracting glare.
(c) Satisfactory direction and suitable colour of lighting.
(d) Suitable decoration to ceilings, walls, floors, and furniture.
(e) and (f) apply specially to schools.
(g) Adequate maintenance.

The question before us this evening is, how does the design of the interior of a building affect the satisfaction of these requirements?

It may probably be assumed that the only variables which we need consider are:—

(i) the mechanical dimensions of a room,
(ii) its surface decoration and
(iii) the provision made by the architect in his design for the accommodation of the necessary lighting equipment.

Of these items, (i) and (ii) have a pronounced effect on (a), (c) and (d), while (iii) affects (b), (c) and (g).

Coefficient of Utilisation.

The effect of room dimensions on the performance of a lighting system can be conveniently studied by means of the tables used for estimating illumination by the well-known lumen method, sometimes called the coefficient-of-utilisation method. The definition of this "coefficient" may be stated quite simply as "that fraction of the lumens from the lamp which gets to the working plane." If half of them get there the c. of u. is 0.5, if two-thirds of them fall by the wayside it is 0.33, and so on.

The tables for finding this coefficient are divided into two stages.

First, the effect of the room dimensions is catered for by means of a figure called a "room index." This is found from a table which gives the room index for a vast selection of widths and lengths of room and for a range of mounting heights of the sources (or ceiling heights in the case of indirect units). Then there is a further table which gives the coefficient of utilisation for any room index and a range of values of the reflection factors of the walls and ceiling, the different sections of the table referring to lighting units with different types of light distribution. These tables are

Table 1.—Room Index.

LIGHTING FITTING	Ceiling	Fairly Light (40 %)		Very Light (70 %)	
	Walls	Fairly Dark (25 %)	Light (50 %)	Fairly Dark (25 %)	Light (50 %)
	Room Index	COEFFICIENTS OF UTILISATION			
DIRECT (A) Open Reflectors such as Standard Dispersive.	A	·39	·43	·39	·44
	B	·43	·46	·43	·47
	C	·50	·53	·50	·54
	D	·55	·58	·56	·59
	E	·60	·64	·61	·65
	F	·65	·68	·66	·70
DIRECT (B) Reflectors with enclosed globe such as Industrial Diffusing Fittings.	A	·26	·29	·27	·31
	B	·31	·34	·33	·38
	C	·37	·41	·39	·44
	D	·43	·46	·45	·50
	E	·48	·51	·50	·55
	F	·52	·54	·53	·58
SEMI-DIRECT Enclosed fittings with major light flux downward.	A	·25	·29	·26	·31
	B	·28	·32	·29	·34
	C	·34	·38	·36	·41
	D	·37	·42	·41	·45
	E	·43	·47	·46	·51
	F	·48	·51	·51	·56
GENERAL Enclosed Diffusing fittings.	A	·20	·24	·23	·28
	B	·23	·27	·26	·32
	C	·29	·32	·33	·38
	D	·32	·36	·37	·43
	E	·38	·42	·44	·49
	F	·43	·46	·50	·55
SEMI-INDIRECT Pendant fittings with major light flux upward	A	·11	·15	·16	·20
	B	·13	·17	·18	·23
	C	·17	·22	·24	·28
	D	·20	·25	·28	·33
	E	·24	·28	·34	·39
	F	·29	·32	·40	·45
INDIRECT Indirect Pendant fittings.	A	·08	·10	·15	·18
	B	·10	·12	·18	·22
	C	·13	·15	·23	·27
	D	·16	·18	·26	·30
	E	·19	·21	·32	·36
	F	·22	·24	·38	·42

reproduced below* and they will well repay a little examination and even some analysis. In the first place it is well to realise they represent the last stage in a series of progressive simplifications of the lumen method as originally described by Harrison

* Reproduced by kind permission from "Modern Factory Lighting." (B.E.D.A. and E.L.M.A. Lighting Service Bureau.)

Table 2.—Coefficients of Utilisation.

Room width	Room length	DIRECT, SEMI-DIRECT & GENERAL FITTINGS						
		Height of fitting above plane of work—FEET						
FEET	FEET	5	10	14	18	22	26	30
8	10	A*						
	12	A*						
	16	B						
	24	B						
	35	B						
	50	C	A					
10	10	B*						
	14	B*						
	20	B						
	30	C						
	40	C	A					
	70	C	B	A				
12	12	B*						
	18	B*						
	24	C	A					
	35	C	A					
	50	D	B					
	90	D	B	A				
16	16	C*	A*					
	30	D	B					
	50	D	B	A				
	80	D	C	B				
	120	D	C	B	A			
20	20	D	B	A				
	40	D	B	A				
	60	D	C	B	A			
	100	D	C	B	B			
	140	D	C	B	B	A		
30	30	E	C	B	A			
	60	E	D	B	B	A		
	100	E	D	C	B	A		
	140	E	D	D	B	B	A	A
40	40	E	D	C	B	A		
	80	E	D	D	B	B		
	140	E	D	D	C	B	B	B
60	60	F	E	D	C	B	B	B
	100	F	E	D	C	C	B	B
	200	F	E	E	D	D	C	C
80	80	F	E	E	D	C	C	B
	140	F	E	E	D	D	D	C
100	100	F	F	E	D	D	C	C
	200	F	F	E	E	D	D	D
120	120	F	F	E	E	D	D	D
	200	F	F	F	E	E	D	D
		7½	15	21	27	33	39	45
		Ceiling height above plane of work—FEET						
		SEMI-INDIRECT & INDIRECT LIGHTING FITTINGS						

and Anderson in 1920.† The method as developed by these authors was based on a division of the light flux from the unit into three components which they termed respectively the "indirect," the "horizontal," and the "direct" components. The horizontal component consisted of that flux which would be emitted by a perfectly diffusing vertical filament having the same candle-power in the horizontal direction as the actual unit. The lower half of this flux was then subtracted from the flux emitted by the unit in the lower hemisphere and the difference was the "direct" component. Similarly, the "indirect" component was the flux emitted by the unit in the upper hemisphere, less the upper half of the "horizontal" component. The method of division will, perhaps, be made clearer by reference to Fig. 1 which gives the polar

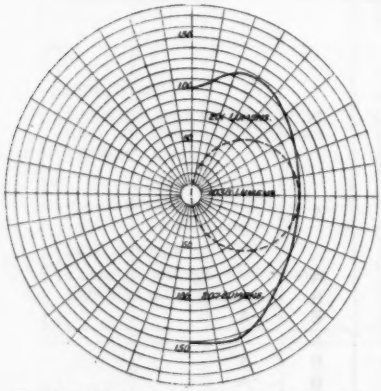

Fig. 1. Division of flux into horizontal, direct and indirect components.

curve of candle-power distribution from an enclosed diffusing fitting. The broken-line circle is the polar curve for the horizontal component and the corresponding flux is 1,038 lumens. The flux emitted by the fitting in the upper hemisphere is 720 lumens, so the indirect component is 720 — ½ (1,038) = 201 lumens, and similarly it is found that the direct component is 207 lumens.

Each of the three components was treated separately and extensive tables were given showing the contribution of each component to the c. of u. for a range of values of room index and different reflection factors of the walls and ceiling. The room index (at that time termed the room ratio) was obtained by means of a formula and not from a table. The formula was, for direct and general lighting units: (1/3 width + 1/6 length)/(mounting height), the width and length referring to the shorter and longer dimensions of the room and the mounting height of the units being measured from the working plane. For indirect and semi-indirect units, two-thirds of the height of the ceiling above the working plane was used instead of the mounting height of the units.

Harrison and Anderson's tables were based on a very extensive and laborious set of measurements made with a number of units giving different flux distributions, mounted at different heights in an experimental room of variable dimensions, with walls and ceiling of variable reflection factors.

A study of these original tables is very instructive. For instance, while the c. of u. for the direct component is practically independent of the reflection factor of the ceiling (as might be expected), the c. of u. for the indirect component is by no means independent of the reflection factor of the walls; in fact, when the ceiling is very light, the effect of the walls is much the same for all three components. This is, of course, due to the large amount of inter-reflection between walls and ceiling when the latter has a high reflection factor.

The calculation involved in the method as described by Harrison and Anderson was considerable, but, of course, there was the compensating advantage that it was directly applicable to a lighting unit with any type of flux distribution whatsoever, as long as this was symmetrical about a vertical axis.

The first stage in the process of simplification was a fairly obvious one. It was the tabulation of the values of room index corresponding to a convenient range of values of width and length of room and of mounting height of units. There

† W. Harrison and E. A. Anderson, Illum. Eng. Soc., N.Y., Trans. 15, 1920, p. 97.

seems to have been a good deal of modification of the formula used. For instance, Parry Moon, in his book "The Scientific Basis of Illuminating Engineering," gives (apparently without reference) the formula (0.9 width + 0.1 length)/(height from floor to ceiling). The tables in Sylvester and Ritchie's "Modern Electrical Illumination," reproduced, apparently, from "Illumination Design Data" (Handbook 2B) of the E.L.M.A. (since the two are identical), seem to be based on yet another formula in which the mounting height of the units does not enter as a simple division. As far as I am aware, the reasons behind this modification were never published, and therefore it is only possible to surmise that the values in these later tables were, in the main, derived empirically. There is some internal evidence for this, since some of the values given are inconsistent with the principle that the room index must be independent of the scale of the room*

If this surmise is correct, the next step taken, as far as the room index was concerned, was quite logical. The actual numerical value of the room index ceased to have any significance, and it was therefore replaced by a letter which preserved the order of the steps but without assigning to them any particular value.

The other part of the tables has also been simplified. It was a natural development for the maker of a particular fitting to calculate, once for all, from the flux distribution of his fitting, the direct, horizontal, and indirect components of the flux, and then to find the combined coefficient of utilisation for a suitable range of room indices and reflection factors. Since fittings tend to group themselves according to the nature of the job for which they are suitable, it is often possible to select a type of flux distribution which will be fairly closely representative of all the fittings in a group. Thus we get the form of table shown above, viz., that which gives, for six main types of light distribution, the coefficients of utilisation corresponding to a range of room indices and certain values of reflection factor.

When we are considering the effect of room dimensions on utilisation, the important thing to notice about this table is that the c. of u. increases as the room index proceeds in alphabetical order. We turn, then, to the first table and see at once that the utilisation goes up (a) as the size of room increases, (b) as the mounting height decreases. A glance at the second table shows, however, that the effect of room dimensions is usually much less than the effect of the decoration. In fact, a change in the tone of the walls from "fairly dark" (25 per cent.) to "light" (50 per cent.) is roughly equivalent to one step in room index, corresponding to a considerable change in either mounting height or room size. Thus the conclusion to be drawn at this stage is that, while it is true to say that the larger the room the better the utilisation, apart from extremes any but large changes in the dimensions of a room or in the ratio of length to width are unimportant as far as the coefficient of utilisation is concerned. The mounting height is so much controlled by considerations other than utilisation that the desire for a higher efficiency must take a minor place among the factors affecting this particular feature of the installation.

Mounting Height.

The chief considerations affecting mounting height have been well stated by Parry Moon (loc. cit., p. 360) as follows:—"The layman seems to have a feeling that the luminaires must be hung as low as possible to get a maximum amount of flux on the working plane. This is by no means true. In fact, a low mounting height is uneconomical for general illumination as a rule because it requires a small spacing.... Therefore more luminaires of a smaller size must be used, increasing the cost of the installation; and since the lamps are smaller, their efficacy is lower. Also, the low-mounting height is generally productive of more glare, and the large number of luminaires dangling from long chains gives a cluttered-up, unaesthetic appearance to the room. It would seem that a general lighting scheme (using commercial luminaires)

* For example, a room of width 16 ft. and length 80 ft., with a mounting height of 8 ft., has an index of 2, while a room of width 20 ft. and length 100 ft., with a mounting height of 10 ft., has an index of 1.5.

is best accomplished in most locations by mounting the units on the ceiling. . . . As in any other kind of design, no all-embracing rules can be laid down. Each installation must be considered carefully as an individual problem."

This desirability of high mounting for the lighting units demands the most careful consideration because it is clearly a vital matter which may well affect the design of the building. Let us, therefore, examine Prof. Parry Moon's points one by one. First of all he mentions the effect on spacing, and it will be clear immediately that in order to attain the same degree of evenness of the illumination on the working plane, the spacing of the units must be directly proportional to their height above this plane. Thus for a mounting height of 7 ft. from the floor the number of units required will be four times that necessary with a mounting height of 11 ft. Now let us suppose that in the former case 75-watt lamps are being used and in the latter case 300-watt lamps. The total lumens from one of the larger lamps will be about 27 per cent. higher than that given by four of the smaller ones. If the room to be lighted is, say, 60 x 100 ft. the room index is F for the lower-mounting height and E for the higher. This change of room index brings about a change of about 7 to 9 per cent. in the coefficient of utilisation if "direct" fittings are used, or about 12 per cent. in the case of "general" fittings. It is therefore plain that, from the point of view of utilisation alone, there is a clear gain of 15 to 20 per cent. by using the greater mounting height.

By far the most important objection to a low mounting height, however, is the glare it causes. This is well recognised and in the lighting regulations for factories, for example, it is laid down that "where any light source in a factory is less than 16 ft. above floor level, no part of the source or fitting having a brightness greater than 10 candles per sq. in. shall be visible to any person whilst normally employed within 100 ft. of the source, unless the angle of elevation of the eye to the source exceeds 20 deg." Similarly, in the report on "The Lighting of Buildings," to which reference has already been made, the recommendation is put forward that in the case of fittings for domestic use "Brightness, when measured over any reasonable area at any angle of view between the horizontal and 60 deg. from the downward vertical, should not exceed 10 candles per sq. in."

It will be noted that in both cases an attempt is made to limit the glaring effect of low-mounted units by prescribing a maximum brightness within certain angles of view. This is, in reality, a palliative and not a cure and the complete solution is to have no lighting unit within the normal field of view of the occupants of a room. The section of "The Lighting of Buildings" which deals with schools is more logical in this respect. Here there is an absolute prohibition of a mounting height less than 9 ft. above the floor and no restriction on brightness when the mounting height is 16 ft. or over. Intermediately there is a limit in a form similar to that used for domestic fittings.

The basis for this use of mounting height as a criterion of glare is the experimental fact that under any given set of conditions the effect of a glaring source is proportional to the illumination it produces at the eye (i.e., its candle-power divided by the square of its distance from the eye) and inversely proportional to about the square of its angular distance from the direction of view. It will be seen at once from Fig. 2 that this leads to the simple result that if the direction of view be assumed to be horizontal, the glare is inversely proportional to the square of the height of the unit above eye-level.

From the point of view of glare-avoidance, then, the golden rule is "mount the units as high as possible."

Prof. Parry Moon's last point, the unaesthetic appearance of a large

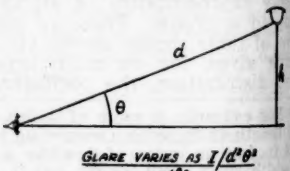

Fig. 2. Effect of mounting height on glare.

number of low units suspended from long chains, I need not elaborate, but there is another argument in favour of high mounting, which he doesn't mention, possibly because it applies mainly to cases in which a single unit, or a very small number of units, is employed, as, for instance, in the rooms of a dwelling house. Here, low mounting leads to a very patchy illumination.

The difficulty of securing adequate mounting height in the modern house is very great, owing to the prevalence of low ceilings, and here I would strongly advocate mounting units as close to the ceiling as possible. In fact, I would go further, and suggest for the serious consideration of architects the provision of a recess in the ceilings, at any rate of living rooms and, possibly, bedrooms as well, for the accommodation of the upper part of a fitting for the general lighting of the room. Fig. 3 shows the form such an arrangement might, perhaps, take. It is, of course, important to

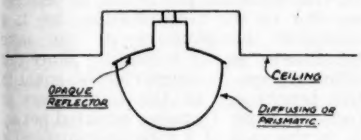

Fig. 3. Unit mounted in ceiling recess.

have a good deal of luminous area below the level of the ceiling; otherwise the ceiling will be dark and, further, a small bright source close to the plane of the ceiling will show up all the brush marks or other slight irregularities in the surface. Fittings for use in this way would probably need to be specially designed. In addition to the requirement already mentioned, it would, of course, be necessary to have the major part of the flux from the fitting emitted in the lower hemisphere and ease of relamping from below should not be neglected.

While on the subject of mounting in or close to the ceiling, it is probably worth mentioning that in dwellings and in other rooms where the ceiling-height is not over, say, about 15 ft., the best form of mounting for discharge tubes is within a few inches of the ceiling, without any kind of shade or reflector whatever. The sockets at the ends should have matt-white outer covers and dark patches or excrescences on the ceiling should be strenuously avoided.

Built-in Lighting.

The mention of special provision by the architect for mounting a lighting unit *in* the ceiling of a room leads us naturally to a consideration of schemes in which all or most of the lighting is from sources placed within compartments specially provided for them in the structure itself. In many cases, the most effective arrangement is some form of artificial window. This is particularly useful when natural daylight is absent or deficient in quantity, and where the use of ordinary artificial lighting units to reinforce the daylight would only serve to draw attention to the deficiency. As an example, take the corridor shown in Fig. 4. Here the daylight is inadequate in certain parts, and, in any case, artificial lighting is needed after dark. The ceiling-height is low (less than 8 ft.), and nothing looks worse than a corridor with a low ceiling and a long row of bright fittings shining into the eyes of anyone walking along it. The obvious solution is a series of artificial windows along one or both sides. These are of very simple design and easy to accommodate, if they are thought of in time, but to add

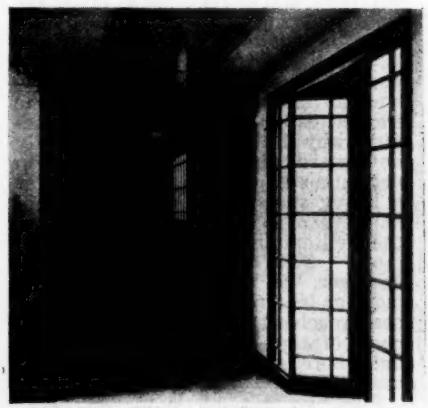

Fig. 4. Use of artificial window in corridor.

them when the building is completed is not only expensive, but usually results in their appearing as the afterthought they actually are; all the illusion of naturalness is destroyed.

In many cases a laylight, lighted by sources placed above it, can be very effective. This, of course, is really an artificial window in the ceiling. The use of artificial rooflights in blacked-out factories has been described by R. Maxted* and has proved very effective. The extensive use of such lights has been made possible by the advent of the discharge tube, and now that this type of source is generally available it may be taken for granted that there will, in the immediate future, be a much more frequent use of artificial windows (and, probably, of other forms of built-in lighting of more doubtful aesthetic value). A brief consideration of the principles of lighting by surface sources may therefore be appropriate here.

Both architects and illuminating engineers are familiar with the various methods which have been devised to facilitate the study of the daylight illumination given by ordinary windows, and a useful résumé of some of these methods will be found in the report on "The Lighting of Buildings" previously mentioned. It might well be thought that the same methods could be directly applied to artificial windows, and so they can as far as the light reaching a given point *directly* from the window is concerned. There is, however, a very important difference between an ordinary window and an artificial window. In the former case nearly all the light admitted by the window has a generally downward direction and, except in very unusual circumstances (as after a heavy snowfall, for instance), not more than 10 per cent. of it reaches the ceiling and upper parts of the room. With an artificial window, however, the light flux is distributed more or less uniformly, so that 50 per cent. reaches the ceiling and the upper parts of the walls and, if these are light, is reflected back and distributed more or less evenly all over the working plane.

From what has just been said it will be clear that the lighting from an artificial window is best studied by dividing the illumination at any point in the room into two parts, viz., the direct and the diffused. The direct component can be calculated by means of any of the methods used for daylight calculations; in fact, these methods are even more reliable when used for artificial windows because the results are not subject to the variations which are inevitable with natural daylight due to lack of uniformity of the sky, and, further, the external obstructions which so frequently complicate the calculations in the case of ordinary windows do not exist in the case of artificial windows. There is just one point to remember, viz., that the figures obtained from the various diagrams, protractors, etc., which have been produced for the analysis of daylight are "daylight factors," i.e., the ratio of illumination on the working plane (in lumens per sq. ft.) to the illumination due to a complete hemisphere of the same brightness as the window. Since this illumination is numerically equal to the brightness of the hemisphere in foot-lamberts (lumens emitted per sq. ft. in the case of a diffusing surface) it follows that a daylight factor of x per cent. corresponds to an illumination of xB lumens per sq. ft. where B is the brightness of the artificial window expressed in hundreds of lumens per sq. ft.

The diffused component of the illumination can best be estimated by a method analogous to that used for ordinary artificial lighting, i.e., by applying a coefficient of utilisation to the upward half of the flux emitted from the window. Some research is needed here to give us a table of values of this coefficient for various room proportions and for a range of values of reflection factors, expecially of the ceiling. If the frieze and ceiling are light and the room of ordinary proportions and if the head of the artificial window is close to the ceiling, it will probably be safe to take a value of about 0.5 for the c. of u.

At this stage it may be convenient to illustrate the method by means of an example. A room 12 ft. wide and

* See, for instance, Illum. Eng. Soc., Trans., Vol. 6, 1941, p. 56.

15 ft. deep is lighted by an artificial window 6 ft. wide and 3 ft. high with its lower edge 3 ft. above the working plane. Thus the window head is 8 ft. 9 in. above the floor and so is practically at ceiling height. It is required that the illumination over the central area of the room, i.e., to within 5 ft. of the wall on the side remote from the window, should be not less than 6 lumens per sq. ft. The ceiling and frieze have a reflection factor not less than 70 per cent.

The "daylight factor" for a point on the working plane 10 ft. from the window and opposite its centre line is found (by plotting on a Waldram diagram or otherwise) to be about 1.8 per cent. Thus, for every 100 lumens per sq. ft. emitted from the window, the direct component of the illumination at the point considered is 1.8 lumens per sq. ft.

The diffused component is obtained quite simply by the lumen method. For every 100 lumens per sq. ft., the total luminous flux emitted from the window is 1,800 lumens, of which half may be assumed to have an upward direction. If the coefficient of utilisation from these be 0.5, the lumens diffused over the working plane are 450, so that the average diffused illumination over this plane is $450/180 = 2.5$ lumens per sq. ft.

Thus the total illumination at the point considered is 4.3 lumens per sq. ft., and therefore to obtain the required minimum of 6 lumens per sq. ft. the total lumens from the window must be at least $1,800 \times 6/4.3 = 2500$. If the window is well designed from the point of view of luminous efficiency, the number of lumens emitted from the window should be at least half those given by the lamps in it. Thus the total luminous output from the lamps must be about 5,000, and so two 80-watt fluorescent tubes should do the job quite satisfactorily.

It may be remarked in passing that in the example just given the window was assumed to be placed as high as possible in the side wall. This arrangement has several important advantages: (a) it reduces the glare to occupants of the room, (b) it produces a more even distribution of the direct lighting, (c) it tends to increase the coefficient of utilisation of the upward light giving the diffused component of the illumination on the working plane.

Glare is a very important consideration in the case of artificial windows in a side wall. With ordinary windows, the lower part of the field of view of anyone sitting near the window is generally occupied by objects in the landscape of much lower brightness than the sky, and if it is not possible to keep the "sill" of an artificial window at a considerable height, the brightness of the window should be graded so that the lower panes are not more than one-quarter as bright as the upper ones. Glare is, of course, avoided altogether with a laylight.

The calculation of the light distribution from laylights would be a simple matter if they could be treated as perfectly diffusing, but generally they are not, and the light distribution on the working plane depends very much on the characteristics of the glass used.

In conclusion, the author would like to express the hope that well-designed built-in lighting may be a common feature of building practice in the immediate future. It has a great deal to recommend it, and probably only a little further study of the matter is all that is required to convince both architects and illuminating engineers of its tremendous possibilities. Emphasis should, however, be placed on the qualification "well-designed." The secret of successful lighting design is the *ars celare artem*. The greatest compliment that can be paid by a layman to a lighting engineer is for him to reply to the question, "What did you think of the lighting?" by the words, "Well, now you ask me, I'm afraid I must confess I didn't really notice it."

DISCUSSION

Mr. A. H. BARNES emphasised the remarks of Mr. Thomas and spoke of the difficulty he found, as an architect, in keeping himself up to date in all the scientific developments of building. The architect to-day was called upon to collate the work of the ever-multiplying branches of industry involved in building, and he was supposed to know something of the language of each. That was so in the case of artificial lighting, and joint meetings between

architects and illuminating engineers could not fail to be of the greatest value. He pleaded with illuminating engineers, however, to use as simple language as possible in their dealings with architects and try to avoid the use of special terms in regard to lighting problems unless they were defined. For instance, the paper spoke of the lumens which got from the lamp to the working plane, but while it defined "lumens," it did not explain what "the working plane" was. That was the sort of thing the architect was up against.

Mr. W. J. Jones cordially congratulated Dr. Walsh on his wizardry in making the problem of illumination appear so simple, but in doing so he had dealt with the problem of basic lighting on the plane of work and had omitted altogether the thing that really interested architects, viz., what was the interplay of brightness of walls and brightness of ceilings. That comment, however, was not a criticism, but was merely intended as a reminder that there was more in this problem than the provision of basic illumination on the plane of work.

He felt the author had brought them all down to earth by saying they should get rid of foot-candles and use the term "lumens per square foot," and he personally would like to see this done. The paper reminded us of the great work of Ward Harrison and the debt we owed to him in this country, which, in his view, had not been sufficiently recognised. There was little doubt that the whole development of illumination design during the past 20 years had been due to the magnificent pioneer work of Ward Harrison and his colleague. It was, as the author stated, wise to go back to the original document in this connection because inconsistencies easily arose if the values were not carefully calculated from the original. It was well to bear in mind that the utilisation method of calculation broke down, to a very large extent, when one was dealing with small rooms. In the case of a room 10 ft. by 10 ft., a great deal more skill had to be employed to assess the amount of light required, and it was interesting to note that some years ago there was a challenge on the Continent to Ward Harrison's work, but after due regard had been paid to the Hefner candle and our candle it was found that Ward Harrison's results merited further investigation, particularly for small rooms. That was one of the points taken into account in the Ministry of Works Report.

With regard to basic lighting, designers seemed to be concerned with brightness ratios of all kinds, and illuminating engineers therefore placed on the architectural profession the task of providing them with more complete data than in the past. Illuminating engineers wanted the ideas of architects as to the relative brightness of different parts of the room because it was only by having that information that illuminating engineers, in turn, could be of assistance to architects in carrying out their conception. He believed the time was coming when the architect would provide a wash drawing of the interior as he sees it, and illuminating engineers would examine that wash drawing from the point of view of the basic illumination required in the room; and an endeavour would be made to reproduce the ratios of brightness shown on that wash drawing.

In welcoming the holding of this joint meeting, Mr. Jones said that artificial illumination is becoming such an important part in building that it was only by co-operation between the architect and the illuminating engineer that installations could be carried out with due economy and due consideration of decoration and careful design which was so much needed.

Mr. M. HARTLAND THOMAS said that, as an architect, he was very grateful for what he had learned at this meeting. Some very definite ideas had been given in the paper of the factors which it was important to use: measurements of rooms, mounting height of fittings, and relationship of various colours, and now Mr. Jones had given a hint that perhaps illuminating engineers would expect the architect to draw out some schedule of lighting, expressed in a rough manner and perhaps in lumens per sq. ft. That was something which architects would like to hear more about.

From an architect's point of view he joined issue with Dr. Walsh with regard to his artificial window. Architects took architecture rather seriously and they did not much like the idea of an artificial window. No objection was taken to it in the case of a theatrical production, but there should be no imitation of a theatrical effect in an everyday situation and, indeed, the illuminating engineer had no business to put an artificial

window in such a place. In a theatre the people went there expecting to be deceived and liked it. Outside the theatre this sort of deception was an embarrassment. There was a feeling among architects that aesthetic truth was something of the highest importance. Already we were surrounded by shams of all kinds, but do not let us add to them.

Referring to fittings, he suggested that we were only just emerging from the primitive age in their design. There had been the oil flame, the candle, gas, and electric light—all point sources. The development of lighting fittings throughout something like three generations had been more or less a process of "botching" to cover the original mistake of perpetuating the point source of light. As the light source became more powerful, the more had it to be covered up, and efficiency reduced, i.e., the amount of light that got through. We were now just beginning to emerge from that. The introduction of the fluorescent tube opened up great prospects with the much larger area of light which it provided. But it was not yet sufficiently diffused in brightness or large enough in area. Dr. Walsh had made the useful suggestion that in a small room with a white ceiling one might put up a fluorescent tube on the ceiling and do nothing more about it. In a recent issue of an American magazine he had seen a workshop illuminated to something like 80 or 90 lumens per sq. ft. with these tubes all over the ceiling about 18-in. apart. Would light built up in that manner cause glare? What was wanted, of course, was a method of illumination which could be used in a manner that was useful and tolerable to the human eye, without elaborate contraptions and the consequent loss of efficiency and awkward appearance.

Mr. H. C. WESTON welcomed Dr. Walsh's suggestion for the use of "lumens per sq. ft.," and expressed the hope that, coming from such an authority, it would carry very great weight. The suggestion to have a ceiling recess was very interesting. Possibly there were serious objections to departing from the conventional flat ceiling, especially in small buildings, but was it not possible to have some modified form of ceiling—perhaps prefabricated in sections—which would assist the lighting engineer by allowing the fitting to be partly recessed.

With regard to artificial windows, what Dr. Walsh had shown was illustrative of a type of large area source of low brightness. However, artificial windows which had been used with fluorescent tubes in factories had been very successful. The point was not so much that they should imitate a window, or even imitate the colour of natural light, as that they should be of large area and low brightness, and be placed in positions from whence it was normally expected light would come.

The crux of this whole problem was contained in the author's closing remarks, where he rightly pointed out that artificial lighting should be so well designed that it could, so to speak, be taken for granted, so that we were not always conscious of it. That was the ideal at which the lighting engineer should aim, and it was one which the architect could help him to achieve by designing interiors with that end in view. The basic lighting for interiors should be provided quite inconspicuously, and decorative lighting added if required. It was a great pity that we had had to deal with point sources which had to be hidden in some way. This had resulted in the design of lighting fittings which came also to be considered as luminous ornaments, but they were very often quite inefficient. In most post-war houses he believed it should be possible to provide the basic lighting for the essential purpose of seeing without being hampered by the need for meeting someone's particular taste for ornament in the fitting itself. One way of doing that was to build the lighting installation in with the building, and if it were possible to afford decoratve lighting in addition, very beautiful effects could be obtained.

Mr. WILLIAM ALLEN said he did not quite share the humility shown by some of his brother architects in the presence of illuminating engineers because he believed that both professions had important contributions to make to the subject. The solution of the problem generally was through good design in buildings, and both professions found common ground there, not in the matter of calculating illumination on the one hand, or supplying drawings on the other, but in the performance of the eye. Importance was attached to that in the Lighting Report, and the architect's contribution to this lay in his control of environment. The whole of the immediate environment influenced the performance of the eye, but Dr. Walsh had obviously excluded this from his paper

deliberately. It was the background to what Dr. Walsh had said, and it was the central problem; the paper dealt only with size and shape of room, mounting, height, etc., as these factors affected the amount of light getting to the working plane. But from that point of view the paper added to the common ground between the professions.

One passage in the paper interested him particularly. It was stated that the chief considerations affecting mounting height had been well stated by Parry Moon, as follows: "The layman seems to have a feeling that the luminaires must be hung as low as possible to get a maximum amount of flux on the working plane. . . . " Possibly Professor Moon was himself in error there. The layman might be much more interested in getting good contrast on the objects of his vision to bring out their shape and make them more easily visible. It was never safe to ignore common practice, because there might be good reason for it. It might be said to be wrong not because common practice was wrong, but because one did not understand why it was right. Scientists had often been misled by such things before, and this might easily be another instance. In fact, with regard to low mounting height and glare, one of the systems which appealed to him as being most successful in practice was in the jewellery department of the Army and Navy Stores, where the fittings were at eye level, and they showed up the jewellery and glassware brilliantly without glare. The fittings were simply opaque tubes with lights inside. A proportion of light went upward as well as down, and the outside of the tube was polished and took in the general colour and tone of the surroundings. Here was a case which cut directly across the theory as stated.

Mr. P. V. BURNETT said that undoubtedly without lighting there would be no architecture. If the architect was to learn to design fine buildings he could not possibly do so unless he learned something about that power which enabled the buildings to be seen. However, the architect's point of view was rather different from that of the lighting engineer: there was not only the light on the working plane to be considered, but when he designed a fine interior he wanted that interior lighted for itself, and for it to be seen to the best advantage. The methods which the architect adopted for interiors must be quite different from those used for exteriors. They must learn something about the effects they could get from different surfaces without going into the question of colour at all, merely by the use of contrasts. It was only in certain fields of architecture that this was being found out, such as in the cinema field. The essential thing was to learn how to use light as light and not as a point fitting.

With others, he also did not like the artificial window, not from the point of view of it being contrary to aesthetic truth, but because he was doubtful whether it was an efficient form of lighting.

Mr. W. E. BUSH said that having just returned after four years in a German concentration camp, he was very little qualified to contribute to this discussion. It was a little ironical, perhaps, that having preached so often against glare, he had been condemned for four years to the use of bare lamps. However, he had found the paper very interesting and the discussion most instructive.

He had attended the meeting with the hope of getting up to date with lighting progress during his absence, but, as far as he could judge, the situation had not changed very much. Indeed, in studying that section of the paper relating to coefficients of utilisation, there appeared little change from standard practice 20 years ago. There were a few requirements here and there, but the fundamentals were the same. The outstanding feature was the considerable interest that architects were now showing in the technique of illumination. Twenty years ago attempts to create their interest had met with little success.

His disappointment with the paper was in regard to Dr. Walsh's single reference to foot-candles. For the purpose for which 8 to 15 ft.c. were now recommended it was the practice 20 years ago to advocate three to five, so that some progress had been made. In those days he was advocating 10 to 12, which was considered by many distinguished members of the society to be extravagant. Now, however, one frequently hears of intensities of from 50 to 100 ft.c. In these circumstances, he felt that it was not necessary to split hairs on coefficients of utilisation when such intensities were likely to be generally employed in modern installations with fluorescent lamps. Unless the long view was taken and due consideration given to this

question, he feared that architects would make the same mistakes in post-war planning as were made in the past, by failing to put sufficient copper into new buildings to take care of the increased illumination intensities which would ultimately be demanded.

Mr. W. T. SOUTER suggested that there should be a standardised and accepted form of presentation of room index data, preferably developed and sponsored by the I.E.S. At the present time all the published tables on this subject differed on their application, making comparisons of utilisation values and lighting design work unnecessarily difficult.

He referred to the comparison test undertaken by Messrs. Harrison and Anderson to check actual illumination values against the calculated figures developed from the three-curve method, the results of which had proved the accuracy which could be obtained. Messrs. Harrison and Anderson's formula was based on room ratios, however, and he suggested that we had probably lost some of this initial accuracy in attempting to develop a quick and simple reference table of typical room sizes. Such a table allows quite a large variation in the room size within a given range without alteration of the room index, whereas a small increase or decrease in dimensions beyond the limits of the range materially changes the room index. Furthermore, the employment of letter symbols does not allow of interpolation to offset this inconsistency. He was of the opinion that a graphical presentation of room ratios offers equal facility in use and enables a more accurate assessment of coefficients of utilisation values to be obtained.

He was gratified with the views expressed by Dr. Walsh in regard to the advantages of built-in lighting, as he had made a similar plea in a paper put before the Society entitled "The Lighting of Public Buildings." Experience of scientifically designed installations of this type had convinced him of the aesthetic advantages gained, together with the avoidance of glare conditions, and he had therefore been very interested in Dr. Walsh's theoretical approach to a similar conclusion.

Mr. A. CUNNINGTON expressed satisfaction that the meeting had drawn such a large attendance, and it had been refreshing to hear the new points of view that had been put forward. He had had an interesting experience with a laylight installed in an underground telephone exchange some years ago when considerable trouble was taken to make this the best possible, although, unfortunately, there was limited headroom. When fluorescent tubes became available he abandoned the laylight and fixed the tubes underneath the ceiling panel, fitted more or less as Dr. Walsh had indicated, using the ceiling as a reflector. This installation was welcomed by everybody, and the staff seemed very pleased to have visible light sources instead of the rather flat effect of the original laylight.

Whilst he was fully appreciative of the excellent theoretical treatment of the problem of built-in lighting given by Dr. Walsh, he felt it necessary to strike a note of warning. He hoped that architects would not be encouraged to incorporate built-in lighting without fully considering the practical difficulties of upkeep. This was an enemy that they always had to be on guard against and, unless ample facility and ample labour were available for keeping these special fittings clean, their initial effect would wear off in a very short time and they might easily bring discredit on the designers.

The great advantage of built-in lighting was that it gave us large sources of low brightness, and he felt certain that this feature would be aimed at more than ever in the future, but he still thought that ordinary lighting fittings might comply with this requirement quite as well as built-in fittings and might, in many cases, be both more attractive and less expensive. In artificially lighted rooms at night we had come, by tradition, to expect light sources to be noticeable, and he did not think there was any special merit in securing lighting of which people were unconscious, as Dr. Walsh had indicated at the conclusion of his paper.

Mr. HOWARD LONG mentioned that it had been suggested that this particular meeting would not be a success because architects would not attend. That had been proved to be quite wrong, and Dr. Walsh had done a great service in simplifying the whole question and enabling the architect to understand it. The real thing that mattered, of course, was how to get the effect, and there was a great deal more in it than providing so many lumens per sq. ft. As to the suggestion that fluorescent tubes should be used exposed, he thought the brightness of

the tubes was really too high for that. In America they had fallen into the same sort of trap. These fluorescent tubes were used, unscreened, in large quantities, but eventually they had to be taken out, not only for over-brightness but for other reasons.

DR. WALSH, in his reply, said that he agreed with Mr. Jones that basic illumination was only the first chapter in the story, but it was impossible in one paper to go farther than he had done. All he could do was to endorse what Mr. Jones had said, and hope that there would be a second and a third chapter. The whole book would ultimately be a long one and a good many chapters would not be written for many years. He was glad Mr. Hartland Thomas had emphasised the distinction between an artificial window and an actual window. The trouble here was the use of the term "artificial window" and he thoroughly endorsed the view that an artificial window should not be an imitation of a real window. Personally, he always looked upon a real window as having a dual purpose; it had to admit light and it should also enable one to see what was going on outside. The artificial window could not do that: If there was any danger that the term might be misunderstood he would rather call it "panel lighting," or use some other term altogether which would avoid the suggestion that the artificial window had any relation to the natural window in its functions. He also agreed with Mr. Allen that it was impossible to have good design of lighting until as much as possible was understood of the reactions of the eye to different lighting conditions. With regard to the instance mentioned of a low mounting height which yet did not cause any glare, he felt that that installation was exceptional and would rarely be suitable in an ordinary building.

Everybody would agree with Mr. Burnett that the architect was interested not only in the lighting on the working plane but also in the lighting of the remainder of the building, because if he designed beautiful buildings we ought to be able to see them. This consideration at once put lighting in a special category, and lighting engineers therefore felt that they had some justification in asking for preferential treatment among the many claims made on the architect to attend to this, that, and the other thing. With regard to Mr. Souter's remarks on the tables of co-efficients of utilisation, he did not think these would be used for highly accurate work, and probably the present scheme was quite adequate for the purposes for which it was employed. He had no knowledge of similar tables for fluorescent lighting, or of any experimental work having been done to develop such tables. When Mr. Sawyer had given permission for the inclusion of the tables in the paper, he rather indicated that there were some values of co-efficients of utilisation for fluorescent sources, but nothing had been published concerning the work on which they were based, and as this matter was clearly in its infancy it would perhaps be better to leave it out of the present discussion.

Troubles were anticipated by Mr. Cunnington with panel lighting, but were they not likely to be just teething troubles? If architects decided that panel lighting was a good thing, designers would undoubtedly get together and find ways and means of getting over troubles such as Mr. Cunnington had mentioned.

He was quite unrepentant with regard to the use of bare fluorescent tubes provided, of course, they were not placed against a dead black ceiling. The tube must have a background with a brightness of the same order—perhaps one-tenth.

It was a delight to everybody to see Mr. Bush back again, and personally he was still more delighted to hear him expressing the same views that he did years ago. He feared Mr. Bush would learn with some disappointment that there had not been the progress which he had hoped for. In the lighting of buildings we were still only using double, or scarcely treble, the values which were current some 10, 15, or 20 years ago, but it was to be hoped that Mr. Bush would take some comfort from a statement in a draft of the Report that "Lighting values have continuously in the past shown a tendency to rise, and there is every reason to expect that this tendency will continue."

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With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form :—"Trans. Illum. Eng. Soc. (London)."

MEASUREMENT OF THE PHOTOMETRIC PROPERTIES OF THE UPPER ATMOSPHERE*

By J. M. WALDRAM, B.Sc., F.Inst.P. *(Fellow)*

(Communication No. 331 from the Research Laboratories of the General Electric Co., Ltd., Wembley, England.)

(Summary of a paper read at the Joint Meeting of the Illuminating Engineering Society and the Royal Meteorological Society, on Wednesday, March 21, 1945.)

This paper describes a part of the work carried out by Sub-Committee G (Photometric Properties of the Atmosphere) of the Civil Defence Research Committee, Ministry of Home Security, under the chairmanship of Mr. P. Good, C.B.E. It is published with official consent.

During the war a number of problems of visibility have arisen, in connection with civil defence and service matters. They concerned, for example, visibility of the ground from the air; air-to-air visibility; camouflage; searchlights and flares used in various ways. Experience showed that full-scale trials were of little real use, for they could not be kept under control; but it was found possible to tackle them by a mixture of laboratory experiment on a reduced scale, and calculation. The atmosphere evidently exercised a profound influence on all problems of seeing or projecting light over long ranges; its effects could be imitated accurately in the laboratory; but there was little information about photometric properties of the atmosphere, particularly above the surface of the earth. This paper describes experiments made to measure these properties, up to altitudes of 30,000 ft. in clean air and up to 3,000 ft. in industrial atmospheres. It is not possible to describe the uses to which the information has been put, but the data which have been obtained have been of much service.

The data were required urgently for the solution of military problems; had to be obtained as quickly as possible; there was no time for elaborate experiments or the development of refined apparatus, and some experimental risks had to be taken. Since the experiments were made during the "blitz," the localities and conditions of experiment were restricted, and the data are not therefore fully representative. Nevertheless some interesting and diverse series of curves have been obtained.

Atmospheric Effects

In any long-range view the atmosphere has usually two effects: it attenuates light passing through it, so that the brightness of distant objects is reduced; and it scatters a veil of light over the scene. Both effects degrade contrasts and impair vision. Since the transmission of the atmosphere is an exponential function of the range, atmospheric effects over long ranges are often the ruling factor in problems of visibility and projection.

These effects are due to scattering and absorption of light caused by the molecules themselves and by small particles of suspended matter, either solid or liquid. The theory of scatter by small particles has been widely discussed and is not dealt with in this paper, which is concerned only with measurements of what occurs.

If a beam of light passes through an element of atmosphere, a small fraction of the incident light is scattered out of the beam, and the beam is therefore attenuated. The fraction scattered per unit length is the "scattering co-efficient." The scattered flux is however not uniformly distributed in space; generally most of it occurs in directions close to that of the original beam, much less being scattered backwards and less still

*** The complete text of this paper will appear in the "Transactions" shortly. A limited edition will be printed, and copies will be issued only to those members who so desire, and who should make application to the Hon. Secretary in due course.**

sideways. The element of atmosphere has in fact a candle-power which varies in different directions, and if the candle-power distribution is known the total amount of flux scattered from the element can be found just as the flux from a lamp can be found from its candle-power distribution. The "candle-power" of the element is expressed in candles per unit length per unit incident flux, and has been named the "polar scatter index."

When pure scatter occurs in the atmosphere, the light is not lost, and the flux abstracted from the original beam reappears in full measure as scattered light. If, however, smoke is present, absorption of light occurs as well as scatter; and the transmission of light through the atmosphere is less than would have been indicated by the scatter alone. Absorption is indicated by an absorption co-efficient exactly similar to the scattering co-efficient. In many cases, however, the absorption is negligible.

For many problems it is necessary to know not only the scattering co-efficient, but the actual distribution of the polar scatter index. Since a knowledge of this distribution enables all the other required information to be calculated, and since there were certain practical advantages in measuring the polar scatter index rather than, say, the transmission, it was made the main target of the work described.

Apparatus

In order to measure polar scatter index a polar nephelometer was devised. In this apparatus a powerful beam of light is projected through an aperture, and a visual photometer measures the brightness of the beam from different directions. It is possible to calculate the polar scatter index from the readings, and to determine it to within 15 deg. of the axis of the incident beam. The apparatus is very sensitive; it has been successfully used to measure, in an aeroplane at 30,000 ft., the polar scatter from air which was clearer than pure air would be at ground level, and when the meteoroligical visibility range was 300 km. When it is used in aircraft, air is brought in to the apparatus in a pipe, the outer end of which faces forwards: the pipe is designed to disturb the air as little as possible.

Air-ground transmission has been measured by determining from the air the apparent brightness of an illuminated white sheet on the ground. The only available telephotometer was difficult for one observer to use from an aeroplane, as he could not easily train the telescope and perform the photometry simultaneously in the conditions of vibration which occur. An apparatus was therefore devised by which one observer kept the line of sight trained, using binoculars, while a colleague operated the telephotometer.

In one series of experiments measurements were made of the brightness of a searchlight beam; a low-brightness photometer was designed by which measurements could be made down to a few millionths of an equivalent foot-candle.

Experiments Made

Three series of ascents have been made in clean air in various parts of the country and at various times of the year, and three series have been made in industrial atmospheres in two localities. A series of observations has also been made at sea level, including many over the sea.

(i) Clean Air.

Series I.—This was the first attempt, and as much information as possible was sought from the experiments. In addition to the nephelometry the air-ground transmission was measured and the brightness of a searchlight beam exposed vertically was determined, and several other observations made, at five altitudes and on the ground. Two ascents were made to 18,000 ft. A satisfactory agreement was found between the various experiments.

Series II.—Several winter ascents were made to 30,000 ft. with the nephelometer only, and a number of unexpected curves were obtained.

Series III.—Further ascents were made in other localities in the summer, with an improved nephelometer; more unexpected results were obtained, including measurements of haze extending to 30,000 ft. and of extremely clear air.

Series IV.—The nephelometer was

carried on a ship during some other experiments; and many other ground observations have been made.

(ii) INDUSTRIAL ATMOSPHERES.

In order to determine the absorption of the atmosphere, as distinct from the scatter, observations were made from a balloon in industrial neighbourhoods. In addition to the nephelometry, the air-ground transmission was carefully measured by an improved version of the technique used in Series I. From the difference between the measured and the calculated transmissions it was possible to determine the absorption and to plot the absorption and scattering coefficients as functions of altitude. Six successful ascents and a number of partially successful experiments were made.

In two interesting ascents, it was found that one was made to leeward of a factory district on a week night and the other was made to windward of the district on a Sunday night, when there should be little smoke present. The first showed considerable absorption and the second showed hardly any. This was an indication that the method was working consistently.

Results

Polar distributions of the polar scatter index were found to show a great variation, though one shape of curve was often found in the lower and ground layers, and in the thicker atmospheres. In this case there is little back scatter, much forward scatter, and a shallow minimum in a direction about 40-70 degs. from the direction of back scatter. Sometimes the minimum is absent, particularly in thicker atmospheres. In clearer air the minimum deepens and the back scatter increases, and the minimum tends to occur nearer to 90 degs. In very clear air the curve is sometimes nearly symmetrical, with equal back and forward scatter; the ratio of axial to sideways scatter is, however, often much greater than would be expected from Rayleigh's equation. But in extremely clear air some distributions have been found which were almost uniform. There seems no correlation of shape of the polar scatter curve with height—in one series of curves obtained from the balloon every shape of curve including the flat one was found, all in the layer 0—2,000 ft. There seems a loose correlation with the amount of scatter, though the reason for this may be partly arithmetical. The distributions obtained in industrial atmospheres did not differ from those in clean atmospheres.

The scattering coefficient generally (but not invariably) diminishes with height; in the upper layers it sometimes followed the curve for density of the atmosphere. There was evident stratification, particularly close to the ground, as would be expected. The amount of scatter varied greatly on various occasions. On one ascent a light haze continued and increased from the ground to 30,000 ft.

The absorption coefficient seemed to be independent of the scattering coefficient; the stratification of the absorbing layers was often different from that of the scattering layers, and sometimes considerable absorption occurred with very little scatter and vice versa. The amount of absorption varied greatly. It sometimes extended above 2,500 ft. There seemed a slight indication that true absorption, in significant amount, tended to be confined to the neighbourhood of the source of pollution.

Usefulness of Results

The use to which the results have been put is not discussed; but it can be said that they have enabled a number of problems to be solved and have opened up a new approach to visibility problems. There is also a hope that it may be possible to determine in some cases the size of the scattering particles from the shape of the curve of polar scatter index; this may be of theoretical interest if it can be done.

There remains a considerable need for statistical information. The work described is not representative of many conditions, and it is hoped that it may be thought worth while to make routine observations of polar scatter.

DISCUSSION

SIR GEORGE C. SIMPSON said how much he appreciated Mr. Waldram's lecture. As a member of the Photometric Properties of the Atmosphere

Sub-Committee he had followed the progress of Mr. Waldram's work with interest and admiration. The problem of visibility is both of practical and scientific interest to meteorologists.

He wondered how many realised that the word "visibility," as now used to indicate the distance one could see, was a meteorological term introduced during the last war. The importance of "how far you can see" was not realised until the meteorologist was asked by the aviator to include this information in his reports.

The first problem was what was meant by "how far you can see"? There was not much difficulty in daylight, for an object was considered to be visible when you could distinguish it for what it was; you must know that the object you were looking at was a horse and not a house or an elephant. Objects were chosen at specified distances, each object being at approximately twice the distance of the previous one, and the distances of the farthest one which could be seen was reported as the "visibility."

The problem, however, was much more difficult at night: what then is meant by "how far you can see"? You might mean how far you could see men moving about, which depended on the amount of light, whether the sky was clear or cloudy, whether there was starlight or moonlight; or how far you could see a light, which would depend on the light, whether it was a 50-watt lamp or a searchlight. So far as he knew, the problem of "visibility" at night had not yet been satisfactorily solved; it certainly was not when he severed his official connection with meteorology. The work Mr. Waldram had been doing would tell us what were the factors on which "visibility" depended and should prove extremely useful to meteorologists. He thanked him for his interesting discourse.

PROFESSOR D. BRUNT said that the aspect of this work which appealed to him most at the moment was that Mr. Waldram's methods should make it possible to ascertain how scattering took place in different layers of the atmosphere. By this means it should be possible to determine how much scatter took place in the dust-laden atmospheres near the ground, and how much farther up.

Dr. C. C. PATERSON, expressing his admiration of the manner in which Mr. Waldram and his colleagues had carried out this work, said he was greatly relieved when he found that the somewhat risky flights they were making were tending to come to an end. Mr. Waldram had not told the whole story of the experiences on these experimental flights. The measuring apparatus interested him greatly for it demonstrated the increasing accuracy with which such apparatus could now be made. As illuminating engineers they realised that the apparatus and equipment they designed did not stand alone. It has to take into account the surrounding conditions which form a part of the lighting system, as also does the eye and the whole human perceptive system. Many engaged in research of this character had spent numerous nights trying to get observations outside when the surrounding conditions were always varying and had had to realise the futility of such efforts. The author and his colleagues had sought to investigate some of the most difficult sets of characteristics of the atmosphere, but from what had been done it now seemed likely that it would be possible to reproduce actual conditions in the laboratory and so be able to solve special cases in the laboratory instead of in the open where complete unreliability of the results is the rule rather than the exception.

Mr. PERCY GOOD said that the lecture this evening was another instance of the happy manner in which those working at the G.E.C. Research Laboratories always presented their papers. Speaking of the origin of this work he expressed regret at the absence of Sir Reginald Stradling, because so much credit was due to him. Some time before the war broke out the I.E.S. offered the services of its expert members to the Government, but the people who received that offer, even though busy with lighting problems, had no knowledge of illuminating matters and did not seem to think there was any special need for expert assistance on the subject. However, when Dr. Stradling was appointed Chief Adviser he promptly invited the co-operation of the Society.

The results of that co-operation would form material for many papers, but what had interested him most was that all the early work was done by the various industrial research associations which had received the fullest possible support from the Chief Adviser. Thus the services of the various industrial laboratories were secured under a proper arrangement. The author, his colleagues, and others who did the work were second to none in this country in their scientific attainments, and he could not help feeling that this type of co-

operation with industrial research workers should be maintained in peace-time. In the course of this work it was apparent that some of the Service research departments had been literally starved in the pre-war period, and if the co-operation with various industrial research departments that had taken place during the war could be continued after the war it would be of immense value to the country as a whole. Dr. Paterson had said that we had been relieved when these experimental flights came to an end. Certainly a great tribute should be paid to all those who took the many risks and strain, and it was with the very greatest regret that the author's colleague was lost during similar work. There had been tremendous difficulties to overcome, and in connection with the work generally a tribute was due to Dr. Stiles, whose work had proved invaluable.

Mr. J. W. RYDE remarked that MR. Waldram had said little regarding the theoretical aspects of the scattering polar curves and added that the form of the polar curves could be calculated from exact electromagnetic theory if the size of the scattering particles were known, as well as the optical constants, i.e., the complex dielectric constant or refractive index of the material of which the particles were composed, and the wave-length of the incident light. But because the curves changed so much with diameter and wave-length it was seldom possible to carry out the reverse process and deduce accurately the mean diameter of particles corresponding to an observed curve. It might be possible in some cases to make estimates in this way, but only when the particles were small. Thus, assuming that the particles were spherules of pure water, the shapes of some of Mr. Waldram's curves were not inconsistent with droplet diameters of between 0.15 and 0.4 micron, although other curves would appear to relate to much larger sizes. With the larger diameters the complexity of the curve increased enormously. Dozens of peaks occurred and some of them were so sharp that they might easily be missed in observing. Further difficulties were encountered with still larger diameters. The whole picture was thus rather complicated. Moreover, changes in the theoretical curves would occur if the particles were spherules of ice and again if they were ice spicules. There was also the difficulty that the particles would not be all of the same size. The statement had been made by the author that scatter and absorption appeared to be independent. This might appear so from his point of view, but the total intensity scattered by a particle was fundamentally related to the absorption per particle through the optical constants. If one took a transparent particle and introduced some absorbing material into it, this would, in general, alter the amount scattered as well as producing absorption in the particle.

WING-COMMANDER R. M. POULTER thought that Mr. Waldram would agree that the various types of scattering obtained were due partly to smoke haze and for the rest to salt particles widely distributed through the atmosphere. The case of haze reported to 30,000-ft. interested him considerably; could one be sure that this scattering was not due either to ice crystals in cirrus cloud or to thin films of frost on any part of the instrument?

Dr. A. R. MEETHAM wished to congratulate Mr. Waldram on his paper. He supposed it might be assumed that the absorption he has been measuring in his balloon experiments was due to some form of atmospheric pollution. He was rather interested to note the statement "the only evidence of absorption has been near industrial towns." This might seem to indicate that particulate atmospheric pollution only existed near industrial towns. But it was quite easy to see from ground observations that certain forms of atmospheric pollution travelled quite a long way from towns. For instance pollution made up of small carbon particles had been known to travel hundreds of miles (and fine sand from the Sahara had been deposited in Switzerland). Ash given off from industrial chimneys included many particles larger than 50 microns, which fell to the ground quite near to the chimney, but it was difficult to believe that such large particles were entirely responsible for the absorption observed by Mr. Waldram.

The AUTHOR, replying to the discussion, said that "visibility," mentioned by Sir George Simpson, was one of the most overworked words in technical language. He would prefer to avoid it, and had proposed elsewhere the term "disappearance range," i.e., the range at which an object just disappeared from sight. It might be necessary, in the future, to define visibility a great deal more closely, and differently according to the job in hand. In reply to Professor Brunt, it seemed to him

that the results indicated that some scattering was taking place in all the layers penetrated—in some more than others—but there was no indication of definite scatter taking place in sharply-defined layers, and practically no scatter outside those layers. He appreciated the reference by more than one speaker to the risks taken by the investigators. Some risks in war-time were inevitable; but the R.A.F. would not allow the investigators to take undue risks; nevertheless, they collaborated in the most willing manner. The happy collaboration between various laboratories and firms, to which Mr. Good had referred, was remarkable; the only object was to get the job done as well as possible. Mr. Ryde had referred to a statement in the paper that scatter and absorption appeared to be independent. That was put forward as a hypothesis which would be consistent with the observations, but not as necessarily the correct explanation. In reply to Wing-Commander Poulter, he said that at present no conclusions had been reached as to the physical causes of the scatter. No observations were made in cloud, because in an aircraft in cloud the variations are too rapid to permit observations. Whether any of the effects were due to ice crystals he did not know. He was certain that condensation on the instruments did not enter; when it occurs they become unusable and the effects are unmistakable. In reply to Dr. Meetham, the evidence for the amount of pollution near industrial towns was very scanty. It turned on one set of observations only. It was significant, however, that he had measured photometric absorption as distinct from scatter; and it might be that it was worth while asking whether the pollution from an industrial area might cause principally scatter without much photometric absorption, except close to the source.

A cordial vote of thanks was given the author at the conclusion of the discussion.

Additions to List of Members

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

SUSTAINING MEMBERS:—

Mersey Power Co., Ltd.....*Representative*: Mr. H. P. Tavernor.
Riche House, Runcorn, CHESHIRE.

W. Pickard and Co., Ltd. .....*Representative*: Mr. G. H. Willis.
Rutland Road, SHEFFIELD, 3.

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Hill, C. G. A. .....36, Westbury Court, Clapham Common, LONDON, S.W.4.
Jackson, Miss Ivy E.,54, Wath Road, Nether Edge, SHEFFIELD, 7.
Makin, F. J. R. .....84, Moss Lane, Timperley, CHESHIRE.
Reynolds, R. ....." Travers," Butleigh Avenue, CARDIFF.
Symons, W. G. .....c/o H.M. Inspector of Factories, 123, West St., SHEFFIELD, 1.
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